PHOTOEMISSION STUDIES ON BNL/AES/JLAB ALL NIOBIUM, SUPERCONDUCTING RF INJECTOR *

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Abstract

Photoelectrons from an all niobium superconducting injector have been generated for the first time. QE of $2x10^{-6}$ at 266 nm and $2x10^{-5}$ at 248 nm, maximum charge of 10 nC in 10 ns and charge/cycle of 0.8 nC were measured. The lower QE observed after laser cleaning, compared to the room temperature measurements, is attributed to the long distance between the cathode and the closest ion pump and the possibility of the laser ablated material adsorbed back onto the cathode surface at cryogenic temperature. No cavity quenching has been observed even at the maximum laser energy of 3 mJ, maximum repetition rate of 250 Hz and maximum charge of 10 nC from the cathode.

INTRODUCTION

In recent years, there has been considerable interest in generating high brightness electron beams with average current exceeding 1 mA[1]. Although superconducting RF (SRF) injectors are ideal for such beams, there has been only limited success in incorporating suitable photocathode in SRF injectors [2]. Quantum efficiency measurements of Nb at room temperature [3] have indicated that an all Nb SRF injector may deliver reasonable current from the Nb cathode, eliminating the complications associated with insertion of a different cathode material. Over the past several years, BNL, AES and Jlab have been collaborating on the development of an all Nb SRF injector. The gun cavity was designed and fabricated by the AES, and tested at Jlab and BNL [4]. The results of photoemission studies from this gun will be presented in this paper.

EXPERIMENTAL ARRANGEMENT

Figure 1 is a photograph of the SRF gun cavity fabricated by the AES. It consists of a single 0.6 cell made entirely of Nb. The Nb on the back wall of the cell functions as the photocathode. It has a single beam pipe port for the transport of the laser to the cathode and the transport of the generated electrons out of the cavity. Two couplers, one for RF input and another to pick up the power stored in the cavity were also incorporated.

* This manuscript has been authored by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. Department of Energy. The United States Government retains, and the publisher, by accepting the article for publication, acknowledges, a world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for the United States Government purposes.

Figure 1: Photograph of 0.6 cell 1.3 GHz SRF cavity.

After fabrication, the cavity was sent to Jlab for buffered chemical polishing and initial RF testing. Subsequently, the sealed cavity was sent to BNL where it was installed in the cryostat inside a soft wall clean room. During installation process, the cavity was exposed briefly to air that resulted in a slight degradation of its RF performance [4].

Figure 2a:. Photograph of the beam transport system. The large cylinder in the background is the cryostat containing the cavity, the blue component in the middle is the focusing solenoid and the horizontal bar in the foreground supports optical elements to transport the laser beam to the cavity.

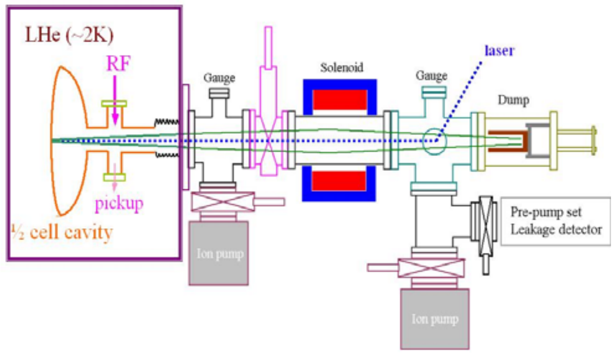

Figure 2b: Schematic of the electron beam transport system.

Figure 2a is a photograph of the electron beam transport line and 2b is a schematic rendition of it. As can be seen in Fig 2b, upon exiting the gun, the electron beam passes through a solenoid to converge onto the beam dump. The beam dump also serves as the Faraday cup to measure the transported charge. It is made up of three components: a collection cup to collect the electrons, a suppressor electrode to reflect back secondary and backscattered particles, and a pre-aperture ring to measure beam halo. The locations of the solenoid and Faraday cup were selected for minimum loss of the electron beam based on PARMELA simulations

Two lasers, a frequency quadrupled Vanadate laser, generating 0.15 W average power at 266 nm in ~ 10ps, with a repetition rate of 81.25 MHz and a KrF excimer laser delivering up to 20 mJ and pulse duration of ~ 10 ns at repetition rate up to 250 Hz were used for photoemission measurements. The UV beam is coupled in to the vacuum system through the laser cross shown in Figure 2b, reflected off a dielectric coated metal mirror slightly off axis to the electron beam, to irradiate the cathode.

The RF power was injected into the cavity from a 100 W power supply in self excited mode. Most of the photoemission studies were carried out with cavity at 4K. For photoemission measurements using the mode locked Vanadate laser, the laser was phase locked to the RF using a fraction of the pick up signal of the self excited loop. Due to the low power of the Vanadate laser and the low QE, most of the photoemission measurements were done using the excimer laser. The pulse duration of this laser covers several RF cycles, resulting in a large energy spread of the electron beam and associated beam loss. On the positive side, since the RF was run CW, synchronization and phase locking of the excimer laser to RF were not an issue.

The photocurrent was measured for a wide range of RF and laser power into the cavity. In each of the cases, the solenoid current was adjusted for maximum signal. The transport loss, calculated using PARMELA, was incorporated into the QE calculations. The QE of the SC Nb before cleaning could not be measured since the current was too low because of the low input power of the Vanadate laser and the high transport loss of the long pulse excimer laser. Room temperature measurements of Nb cathode has shown that significant improvement in the QE can be achieved by laser cleaning the cathode [5]. Figure 3 shows the dependence of QE on the RF field after laser cleaning

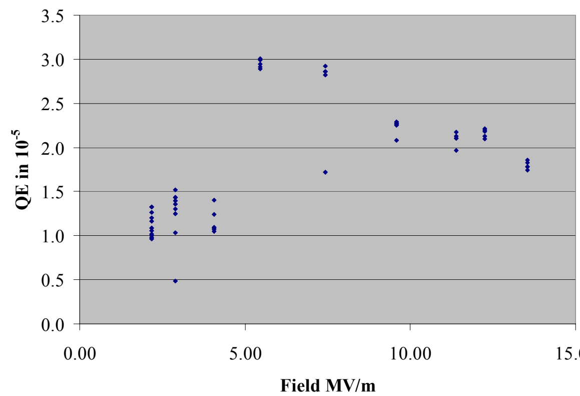

Figure 3: QE vs field after laser cleaning using excimer laser.

After cleaning, the QE was measured to be ~ 2×10^{-6} at 266 nm and 3×10^{-5} at 248 nm. Unlike the room temperature measurements, QE $>10^{-4}$ after laser cleaning could not be obtained. In order to minimize the time lag between the laser cleaning and QE measurements, the laser cleaning was done when the cavity was cold. The low QE measured could be attributed to the fact that the closest vacuum pump is more than a meter away from the cathode and the cathode acts as a cryopump, attracting contaminants and laser ablated material, rendering the laser cleaning process ineffective.

In order to extract maximum charge from the cathode and investigate the possibility of cavity quenching due to the laser beam, the excimer laser energy was increased to ~ 3 mJ. From the Faraday cup signal, the maximum charge and the charge per cycle delivered by the cathode were estimated to be ~ 10 nC and 0.8 nC respectively. Based on the QE, for this laser energy, one would expect these numbers to ~ 12 nC and 0.96 nC in the absence of space charge. Fig. 4 illustrates the dependence of the charge on the field in the cavity. The linear increase in the extracted charge at low RF field for constant laser energy is indicative of strong space charge effects. The electron yield approaches space charge free operation beyond 7 MV/m. The temporal profile of the Faraday cup signal was very similar to that of the laser, both measured using an oscilloscope of 300 MHz bandwidth. The RF signals from the cavity did not show any sign of quenching at these high laser energies, charges and repetition rate of 250 Hz.

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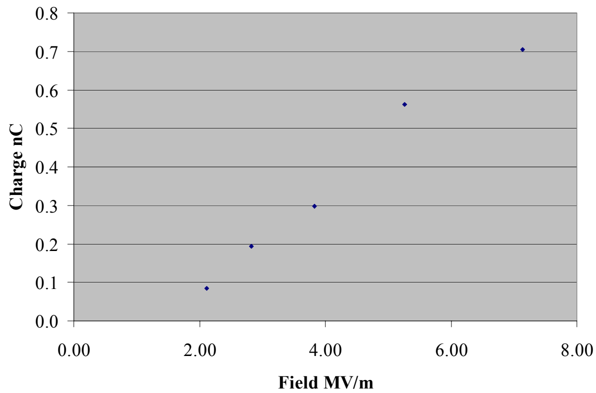

Figure 4: Charge vs cavity field for 3 mJ laser energy. The linear increase of charge at low fields is indicative of the presence of space charge effects. Onset of space charge free emission requires fields> 7 MV/m for this configuration .

In conclusion, photoelectrons have been generated for the first time from an all niobium superconducting injector. QE of $2x10^{-6}$ at 266 nm and $3x10^{-5}$ at 248 nm and charge/cycle of 0.8 nC has been measured on laser cleaned Nb. The QE of the laser cleaned Nb is not as high as anticipated, based on the room temperature performance of Nb. This could be attributed to the fact that the laser cleaning of the cavity cathode was done at low cathode temperature where the laser ablated material could be adsorbed back on to the cathode. Preparations are underway to laser clean the cathode at room temperature prior to cooling as well as testing Pb cathode mounted on a RF choke joint. Both these approaches are expected to increase the QE of the cathode, paving way to all metal > 1 mA SC injector.

ACKNOWLEDGEMENT

The authors would like to acknowledge the expert technical assistance of D. Pate, J. Walsh and M. Montemagno.

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